Quantifying Lumber Value Recovery from Beetle-killed Trees

Laszlo Orbay and Derek Goudie

Mountain Pine Beetle Initiative
Working Paper 2006–09

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Abstract

Forintek's sawmill simulation tool, Optitek, was used to estimate lumber and by-product value yields from a sample of logs with defects caused by mountain pine beetle. A model of a typical British Columbia interior sawmill that manufactures dimension lumber using technologies currently common in the industry was used to process the log data—first without defects, and then with defects present. The resulting relative value yields showed the loss in value caused by the beetle-induced damage. Check damage in a log was the most significant defect and a check severity index was developed to segment the log sample according to damage level. A correlation was found to exist between beetle-induced checking (as measured by the check severity index) and the value of the products obtained from the logs.

Sawmill simulation was also used to estimate potential value recovery gains that could be attainable through use of emerging, innovative lumber manufacturing technologies. The sawmill model was modified to simulate the use of scanners and optimisers capable of detecting defects and considering their impact when generating optimal breakdown and sawing solutions. The data describing damaged logs were re-processed using the updated sawmill model. Results showed significantly higher value yields than did those obtained from the model of the sawmill using current technologies.

The Optitek sawmill model and the check severity index are promising decision support and research tools that, with some refinement, will allow more accurate evaluation of economic opportunities associated with logs from beetle-killed lodgepole pine, based on visible external defects.

Key words: Lumber value recovery, lodgepole pine, mountain pine beetle, check severity, sawmill simulation tool, log defects

Résumé

Optitek est un outil élaboré par Forintek pour simuler le fonctionnement d'une scierie; on l'a utilisé pour estimer le rendement en bois et en produits de récupération à partir d'un échantillonnage de billes ayant des défauts engendrés par le passage du dendroctone du pin ponderosa. On a eu recours à un modèle de scierie typique de l'Intérieur de la Colombie-Britannique, qui produit du bois à dimensions spécifiées au moyen des technologies utilisées en ce moment dans cette industrie, pour traiter les données relatives aux billes, premièrement celles sans défaut et ensuite celles comportant des défauts. Les rendements calculés en ce qui a trait à la valeur relative résultante ont montré une perte de valeur causée par le passage du dendroctone. Les gerces dans une bille sont le défaut le plus important et un indice de sévérité de la gerce a été mis au point pour diviser une bille échantillon en fonction de l'ampleur des dommages. Une corrélation existe entre les gerces causées par le passage du dendroctone — mesure établie par l'indice de sévérité de la gerce — et la valeur des produits fabriqués à partir des billes.

La simulation du fonctionnement d'une scierie a également permis d'estimer les gains éventuels associés à la récupération de la valeur et rendus possibles par l'utilisation de technologies émergentes et novatrices de traitement du bois. Le modèle de fonctionnement d'une scierie a été modifié pour simuler l'utilisation de scanneurs et d'optimiseurs capables de déceler les défauts et d'évaluer leurs répercussions au moment de la génération de solutions optimales en ce qui concerne le débitage. Les données décrivant les billes endommagées ont été analysées de nouveau à l'aide du modèle de scierie mis à jour. Les résultats ont montré des rendements considérablement plus élevés que ceux obtenus à l'aide du modèle de fonctionnement d'une scierie ayant recours aux technologies en cours actuellement.

Le modèle de fonctionnement d'une scierie Optitek et l'indice de sévérité de la gerce s'avèrent être des outils prometteurs d'aide à la décision et de recherche qui, une fois raffinés, permettront une évaluation plus précise des possibilités économiques que le pin tordu latifolié endommagé par le dendroctone du pin ponderosa présente en fonction des défauts externes visibles des billes.

Mots clés : récupération de la valeur du bois, pin tordu latifolié, dendroctone du pin ponderosa, sévérité de la gerce, modèle de fonctionnement d'une scierie Optitek, défauts des billes

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1 Introduction

The current outbreak of mountain pine beetle (MPB), Dendroctonus ponderosae Hopkins, is the largest in Canada's history. As it continues to spread, the associated economic, environmental and social challenges continue to mount. This is particularly true in British Columbia, with the province's abundant supply of the beetle's favoured host, lodgepole pine (Pinus contorta, Dougl. var. latifolia Engelm.). The infestation now covers more that 8.0 million hectares in British Columbia and is projected to kill up to 80 per cent of the province's merchantable and susceptible lodgepole pine.

Policy makers recognize the urgency associated with recovering as much value as possible from the affected resource. As a consequence, they continue to allow for greater use of dead and dying trees by increasing annual allowable cuts of timber in infested areas. To handle increased harvest levels, many lumber manufacturers have significantly increased manufacturing capacity. Operating practices are also being re-evaluated as the industry adapts not only with respect to capacity but also to changing quality characteristics of logs now being processing.

The effect of beetle attack on the wood and the nature of induced defects are reasonably well understood. The insect carries a fungus that spreads throughout the sapwood, leaving behind a permanent blue or grey stain. As the tree dies and the moisture content (MC) falls below the fibre saturation point (approximately 30%), checks develop. As long as drying continues, the number and the size of these checks increase. Although the stain is restricted to the sapwood and affects only the appearance of the wood, checks are variable with respect to location, shape and number, and have a significant detrimental impact on both lumber volume and value recovery.

Sawmillers generally have a solid understanding of the relationship between the qualities of the timber they process and the expected volume and value of lumber and by-products. However, this is not the case when their mills are processing beetle-attacked wood in varying stages of degradation. Although sawmill-performance measures are known to vary with level of beetle-induced degrade, the precise nature of this relationship is not well known

Mills will continue to process higher volumes of beetle-attacked pine and, as average time since death of the trees increases, the degree of degrade and the variability in quality present in the logs will also increase. The changing resource will impose on sawmillers the need for adaptability with respect to processing strategies as well as targeted products, which in turn will dictate the need for a greater understanding of the relationship between beetle-induced defects and the expected yield of lumber volume and grades.

As log quality continues to decline, and as value losses relative to healthy logs continue to mount, sawmillers will increasingly look for potential recovery gains from emerging technologies. Scanners that detect checks and bluestain, and optimizers that use defect data to generate breakdown patterns and sawing solutions show some promise; however, the degree to which value losses can be reduced using these innovative processing technologies has not been studied.

In this project, Optitek, Forintek's sawing-simulation software, was used to estimate value losses in logs resulting from mountain pine beetle attack. Lumber value recovered from healthy logs was used as a base case from which to estimate the impact of increasing levels of bluestain and checks. The extent to which emerging technologies might mitigate those losses was also investigated.

2 Objectives

- To estimate lumber value loss as a function of degree of beetle-induced defects in logs.
- To estimate the degree to which the value loss resulting from beetle-induced defects can be reduced by using emerging processing technologies.

3 Materials and Methods

3.1 Log data

Due to the scope of this analysis and the profile and specific characteristics of the log sample required as input for the simulations, the data were collected as part of a separate but parallel initiative carried out under Natural Resources Canada, Canadian Forest Service's Mountain Pine Beetle Initiative Project # 8.34: True Shape and Defects Data from MPB Affected Stems. Selection of logs and collection of log data are summarized here.

An initial sample of 233 beetle-damaged logs was selected from the logyard of Tolko Industries Ltd. sawmill in Quesnel BC. Although it was not possible to unambiguously identify the colour stage of any of the sample logs, the logs were deemed to represent all levels of damage commonly associated with the green, red and early grey stages of beetle-induced deterioration. The sample did not include logs with the most severe beetle-induced damage associated with the later grey stages of MPB attack because such logs were not present in the logyard at the time the sample was assembled. The limited distribution of beetle damage levels in the sawmill's log yard and in other logyards in the region at that time was a consequence of the availability of high volumes of fibre with light to moderate levels of damage, coupled with a lack of compelling incentive to bring in fibre with more severe beetle damage.

After logs were selected, they were debarked and moved to the infeed of the mill's large-log line. The logs were individually conveyed through the mill's true-shape–scanning system, which collected size and shape data, and through Forintek's bluestain and checkdetection system, which collected digital images of the sides and end surfaces of each log. The digital image data were subsequently processed to delineate bluestain and check defects, and the data describing these defects were merged with the true-shape data. The true-shape and beetle-defect data were then transposed into a format suitable for Optitek.

3.1.1 Selection of sub-sample of 40 logs

Two pilot simulation studies were conducted prior to beginning the detailed analysis required to meet the primary objectives of the project. The purpose of the pilot simulations was to provide approximations of the distribution and magnitude of expected recovery losses, thereby facilitating the selection of the sample logs to be used in the final and more detailed simulation study. In the first pilot simulation, all of the log data were modified to remove descriptions of the beetle-induced defects and then processed as though the logs were healthy. In the second study the log data were processed with the MPB damage present.

In all but a few of the logs, the sapwood was fully bluestained and most of the logs had checks that were less than 2.5 cm in depth. The results of the pilot simulation indicated that value recovery from logs with bluestain but only minor checks was very close to the yield from healthy logs with no beetle damage. There are two likely explanations for these results: the shallower checks are either removed by the chipping heads during primary breakdown, or have minimal or no impact on the grade of the lumber produced; and the J-grade product in which bluestain is restricted does not permit wane, meaning that little came from the stained sapwood region where pieces are more likely to have wane.

Since a primary objective of the study was to evaluate losses caused by various levels of beetle damage, the final and detailed simulation study used only those sample logs for which the value recovery loss was deemed to be significant. A minimum loss in value recovery of $2.00 per cubic meter was chosen to be the cut-off point, above which the defect caused by mountain pine beetle merited inclusion. Based on that criterion and results of the pilot sawing simulation study, 40 sample logs were selected from the original 233 logs that were evaluated. External shape characteristics of the 40 logs are provided in Appendix 1, while Table 1 provides a summary of these characteristics.

Table 1: Descriptive statistics of 40 sample logs.

Statistic	Small-end Diameter (cm)	Large-end Diameter (cm)	Sweep (cm/m)	Taper (cm/m)	Length (m)	Volume (dm3)
Minimum	14.5	19.8	0.16	0.36	3.00	92.1
Maximum	30.1	37.3	1.46	2.11	6.24	587
Mean	23.8	28.9	0.61	1.14	4.42	280
Std. Dev.	4.48	5.77	0.24	0.45	1.37	168

3.2 Sawmill simulation

Optitek is a sawmill-simulation tool developed by Forintek in 1994. The software was designed using object-oriented programming language concepts, and it allows users to accurately model the components of the manufacturing system that affect lumber volume and grade recovery. Input requirements include descriptions of the equipment and processes used in the mill, and the mill's targeted product sizes and grade rules, as well as data describing the raw material supply. The software uses these inputs to identify breakdown patterns, sawing solutions and, ultimately, lumber and by-product outturns that yield the highest volume or value. Results can then be summarized for groups of logs.

Optitek was used to estimate value recovery associated with logs with varying degrees of beetle damage. Optitek is uniquely suited for this work because the program is able to simultaneously use external and internal log-defect data to generate optimal breakdown and sawing solutions. Two sawmill models were developed to simulate the processing of the sample logs. The first represented a typical sawmill with equipment and technology commonly used in the industry today. The second model was of the same sawmill, but as if it were modified to use emerging technologies aimed at extracting more value from logs with beetle-caused defects.

3.2.1 Sawmill specifications

Every lumber manufacturing operation is unique, with a distinct combination of raw materials, equipment, processing practices and products. However, sawmill design and targeted products reflect the characteristics of the available fibre. Most sawmills in British Columbia's interior, including most of those cutting beetle-killed timber, were designed to process SPF, comprising a mix of interior spruce (white spruce, Engelmann spruce and their hybrids) lodgepole pine and subalpine fir. Many produce dimension lumber by using similar technologies with a common focus on productivity and lumber recovery within narrow grade yield targets. Although each of these SPF mills is unique, their designs are sufficiently similar to allow identification of a typical configuration.

The typical sawmill used in this project, shown in Figure 1, was designed based on the project team's experience in working with sawmills in British Columbia, and in consultation with individuals working in the lumber manufacturing industry. The mill model consisted of a large-log line and a small-log line. Both log-infeed systems were equipped with a true-shape scanner and

an automatic log turner, which allowed optimized log rotation in 15 ° increments. The large-log line used a three-sided canter and circular saws cutting a maximum of two sideboards on each side of the centre cant. Depending on log size, the bottom chipping head profile chipped a 2 x 3 or 2 x 4 spline board. The small-log line was a 2-sided canter, close-coupled with a vertical double-arbor gang saw, producing lumber pieces from the centre cant only. Cant positioning at the gang saws was accomplished by pushing the bottom opening face against a linebar. The cants were not re-optimized, and the saw lines matched the solution determined by the canter optimizers.

Boards were sawn to final sizes by an optimized board edger and an optimized trimmer with moving fence. Optimum board positioning at the board edger was simulated by choosing from five possible split taper positions in half-inch steps within the offset range of –1 inch to +1 inch. Fence movement at the optimized trimmer was simulated by allowing movement in 4-inch increments within a range of 0 inches to 24 inches. Board lengths ranging from 8 feet to 20 feet were thus possible.

The second mill model, intended to simulate the application of emerging technologies, employed scanners capable of scanning log ends as well as log surfaces along their full lengths, and detecting any checks and bluestain. The mill also used scanners at the board edger and the trimmer to detect these defects on lumber surfaces. Optimizing systems were modified to allow consideration of the impact of these defects when identifying and evaluating possible log breakdown solutions, so logs were rotated and otherwise positioned, and boards were edged and trimmed so as to minimize loss in value caused by beetle defects.

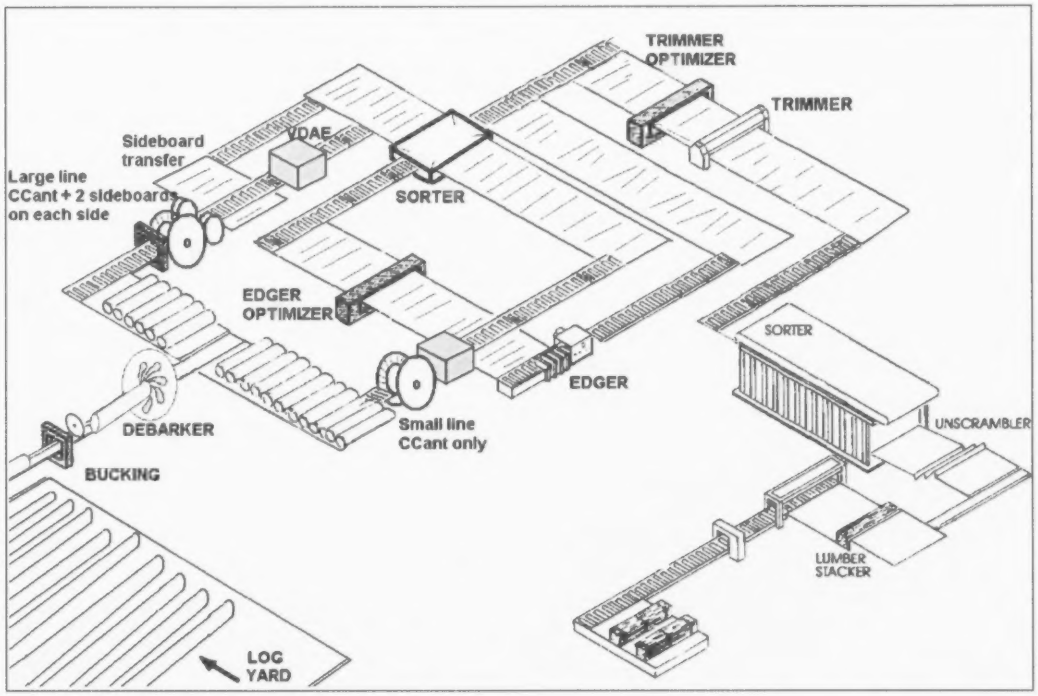

Figure 1: Sawmill layout

3.2.2 *Product specifications*

The simulated sawmill was designed to produce dimension lumber for the North American market; therefore, the product mix included lumber with a nominal thickness of 2 inches and nominal widths of 3, 4, 6, 8, and 10 inches. Nominal targeted lengths ranged from 8 feet to 20 feet, in increments of 2 feet. Table 2 shows the rough green target size for each of nominal size. Two additional products were included in the product mix: an appearance grade commonly referred to in the industry as J-grade, and a strength grade known as MSR (machine-stress–rated).

Table 2: Nominal and rough green target sizes.

	Lumber sizes (inches)		Lumber lengths	
	Nominal	Rough green target	Nominal (feet)	Rough green target (inches)
Thickness	2	1.67	8	97.50
Widths	3	3.00	10	121.45
	4	3.80	12	145.65
	6	5.80	14	169.85
	8	7.60	16	194.05
	10	9.75	18	218.25
			20	242.50

The grade rules for dimension lumber included in the product mix are derived from those defined by the National Lumber Grades Authority (NLGA), and are shown in Table 3. The grade rules for the J-grade and MSR grades, also in Table 3, were determined in consultation with several sawmills that produce such products.

Table 3: Lumber grades used in sawing simulation

Optitek Grade	Industry Grade	Max. Wane (%) T	W	L	Max. Shake L	W	Thr	Edg	Max. Splits	Max. Stain
1	J-grade	0	0	0	24"	1/32"	NP	NP	NP	2%of vol.
2	MSR	25	25	100	24"	NL	NP	NP	Pc W	NL
3	No.2&btr	33	33	100	36" or ¼ L 24"	NL NL	NP Yes	Yes NP	1.5 Pc W	NL
4	No.3	50	50	100	1/3L	NL	Yes	Yes	1/6 Pc L	NL
5	Economy	50	75	100	80%	NL	Yes	Yes	1/3 Pc L	NL

Notes: T=thickness; W=width; L=length; Thr=through; Edg=edge; NP=not permitted; NL=no limit; Pc = piece

Lumber prices per thousand board feet (Mfbm), along with corresponding piece values, are listed by lumber size and grade in Appendix 2. The grading subroutine of Optitek considers only defects listed in Table 3; however, other defects such as knots are also important in setting the grade of a piece of lumber. It was thus necessary that piece values be calculated as weighted averages using grade outturns typical of those experienced by sawmills in the British Columbia interior. A detailed description of the piece-value calculation is provided in Appendix 3.

Chips and sawdust were considered to be saleable by-products, and their value was included in all of the considered solutions. By-product prices are shown in Table 4. Chip prices have fallen since the creation of the model's product file. This change would magnify the detrimental impact of beetle-induced defects on value recovery, but would not have a significant effect on results of these simulations.

Table 4: By-product prices

By-product	$/Bone Dry Unit	$/Metric Tonne	$/dm^3 of Solid Wood
Chip	52.00	47.77	19.50
Sawdust	8.50	7.81	3.20

3.2.3 Overview of analytical approach: comparative simulations

The sample logs were first processed using the model of the mill with current technologies. All defects were "removed" from the logs: this initial simulation provided base-case estimated value recoveries from logs with no beetle defects. Using the same mill model, the same logs were processed again, with defects present, so that the breakdown solutions were the same. Defects were evaluated during simulated grading of the lumber, thus providing an estimate of the value loss attributable solely to defects caused by MPB when using current technology.

The same log data, again with defects, were processed using the sawmill model equipped with innovative emerging technologies. The impact of checks and bluestain was considered by optimizers during selection of the highest-valued breakdown patterns and sawing solutions so that value yield was as close as possible to the yield from the same log with no defects. This provided an estimate of the potential benefits of using emerging technologies.

The methodology used in this analysis, and the hypothesized results, are shown graphically in Figure 2. The difference between value recoveries from healthy logs (H) and damaged logs when current processing technologies (CT) were used was calculated for groups of logs A, B and C as:

$$\mathbf{AH - ACT;} \quad \mathbf{BH - BCT;} \quad \mathbf{CH - CCT}$$

The difference between recoveries from damaged logs processed with emerging technologies (FT) and with current processing technologies was used to estimate the extent to which these emerging technologies might reduce losses caused by beetle defects, and was calculated for groups of logs as:

$$\mathbf{AFT - ACT;} \quad \mathbf{BFT - BCT;} \quad \mathbf{CFT - CCT}$$

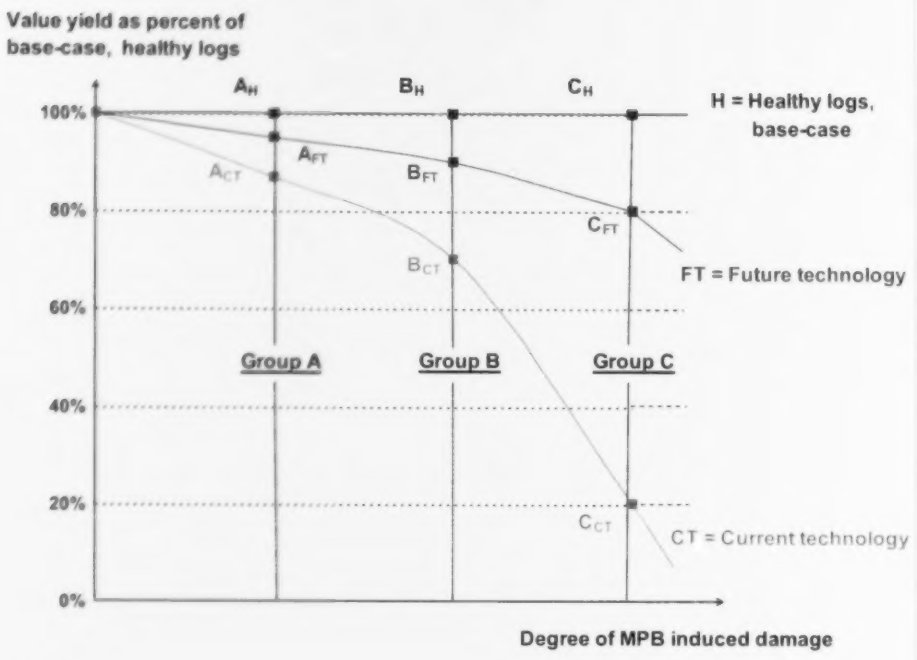

Figure 2: Hypothesized relationship between degree of MPB damage, value yield and technology

3.2.4 Model validation

When a complex system such as a sawmill is modeled, validation is necessary to determine the extent to which the model is a realistic representation of the actual system. In this case, model validation was accomplished by means of visual inspection of logs, sawing solutions and lumber products.

To ensure that defects present in sample logs were accurately represented in log models used by Optitek, sequential log cross-sections were analyzed using Forintek's log-image viewer. On each cross-section, the presence of bluestain in the sapwood was confirmed. Sequential cross-sections were also analyzed to evaluate the number of checks and to ensure that measured check depth, length and spirality were accurate.

Breakdown patterns and sawing solutions were also validated by means of visual inspection of log end-views, using Optitek's display tool. Examples of breakdown patterns, showing a log in the healthy condition (i.e. with defects ignored) and with defects included, processed using current and emerging technologies, are shown in Appendix 4, along with tabulated yields. Since internal-defect recognition is a relatively new program feature, care was taken to validate its accuracy, as well as the accuracy of the associated lumber-grading subroutines. Individual boards were evaluated using the display feature and were assigned a manual grade. These grades were then compared to the grades assigned to the board by Optitek. In all cases, the program accuracy was confirmed, and results therefore deemed to be validated.

4 Results and Discussion

4.1 Value yields and the benefits of emerging technologies

From the perspective of the sawmiller, value yield per unit log volume is the most important measure of the impact of changes in the quality of the raw material supply. As discussed, sawmill equipment and technologies, as well as targeted products and associated cutting programs, are selected or designed to extract as much value as possible from available fibre. The analyses of the output from these simulations are thus focused on comparing the value per unit log volume, of the lumber and by-products from a log with defects caused by MPB against the value of the products from the same log without any defects.

The results of the simulations are shown in Appendix 5: absolute value yields from each log are reported, first for healthy logs sawn with current technology, then for logs with defects also sawn with current technology and finally for logs with defects sawn with future technologies. A second table in Appendix 5 reports normalized recoveries: value yields from logs with defects as a proportion of yields from the same logs with no defects. The absolute values of the yields and losses using current and emerging technologies are summarized in Table 5, and the summary of normalized values is shown in Table 6.

Table 5: Summary statistics describing absolute value yields by technology level

	Value yield by log condition and level of technology ($/m^3)			Value loss due to defect by technology ($/m^3)		Value loss mitigated by emerging technology ($/m^3)
	Healthy Current	Defects Current	Defects Emerging	Current	Emerging	
Minimum	60.23	49.91	59.37	0.21	0.00	0.00
Maximum	126.46	112.07	120.62	39.11	14.90	33.50
Mean	103.31	88.58	98.45	14.73	4.86	9.87
Std. Dev.	13.57	16.12	12.36	10.33	3.71	8.77

Table 6: Summary statistics describing normalized value yields by technology level

	Value yield by log condition and technology as proportion of healthy log			Value loss by technology (prop. of healthy log)		Value loss mitigated by emerging technology
	Healthy/ current	Defects/ current	Defects/ emerging	Current	Emerging	
Minimum	1.00	0.561	0.877	0.002	0.000	0.000
Maximum	1.00	0.998	1.000	0.437	0.123	0.376
Mean	1.00	0.857	0.954	0.144	0.046	0.098
Std. Dev.	0	0.105	0.032	0.110	0.032	0.095

Despite a lack of severely checked sample logs the nature of the impact of beetle attack on value of the resource is well demonstrated by the wide range of values recovered from damaged logs relative to values recovered from the corresponding healthy logs. The log with the greatest value loss, log 214, yielded 56% of healthy log value, while log 195—least affected by the attack—yielded 98.8% of healthy log value. This reflects the wide range of check damage in the sample logs. Log 195 was 10 feet long with a top diameter of 8.3 inches, and had a single check only 17 inches long with a depth of approximately 2 inches. Log 214 was 13.25 feet long with a top diameter of 7.25 inches; there was only one check present, 2.5 inches deep, but it ran the full length of the log.

Tables 5 and 6 also show the value loss potentially mitigated through application of emerging technologies simulated here. The increase in value recovery from damaged logs processed using emerging technologies relative to current technologies is significant. At present, defects caused by beetle attack result in an average value loss of 14.4%; however, through application of scanning and optimizing systems that detect and optimally position defects, only 4.6% of the value of the healthy log is lost. In theory, value loss associated with the most severely checked log was reduced from 43.9% of the healthy log value to only 12.3%.

Value recoveries from the 40 sample logs are shown in Figure 3, ranked by value recovery as a percentage of healthy log condition. Three recovery points are displayed for each log. The value yield from the healthy log, the uppermost horizontal line, is presented as the maximum value attainable. The lower line shows the yield from the same logs with defects processed with the same current-generation technologies, while the middle line shows yields from the same beetle-killed logs processed with emerging technologies. The graph thus highlights, on a log-by-log basis, the gains possible through emerging technologies.

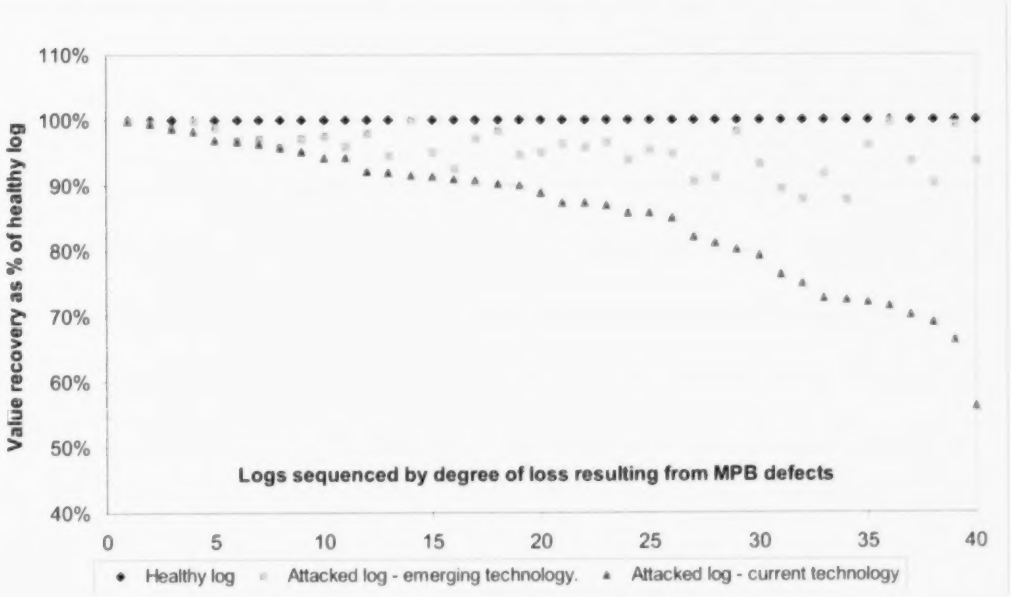

Figure 3: Value recovery from damaged logs relative to healthy logs

Although the benefits of emerging technologies appear to be significant, care must be taken when interpreting these relative values. Many of the beetle-attacked logs had one long, deep and straight check. Although this was representative of the logs that were available during the process of selecting sample logs, it is not necessarily the case for all beetle-attacked logs. The value gains achievable through emerging technologies also reflect an idealized manufacturing environment that cannot be fully realized in practice.

In the sawmill model, defects present in each log are accurately detected and measured, including the depth of the checks, so optimizers can use defect data in an ideal manner. Although scanners capable of detecting stain and checks are presently being brought to market, the sensitivity and accuracy of these systems have not been proven. Further, in the modeled environment, the equipment positions all logs and lumber precisely as the optimizers had positioned them during selection of the optimal solution—which does not always occur in a sawmill.

4.2 Value yields associated with checking characteristics

The checking that occurs as a result of attack by MPB has a significant and detrimental effect on lumber volume and value recoveries, however, there is presently no established systematic method for describing severity of checks present in a log. Consequently, to estimate lumber value loss as a function of the degree of beetle-induced defects, a primary objective of this work, the check severity index was formulated as an indicator that would quantify the degree of check damage present in a log. The index considers three checking damage indicators: 1) average check depth as a percent of the radius of the log; 2) average check length as a percent of the length of the log; and 3) number of checks. Measures of each component of the check severity index are listed for the sample logs in Appendix 6. Derivation of the check severity index initially developed as part of Mountain Pine Beetle Initiative Project # 8.34 is shown in Appendix 6. Figure 4 shows the severity of checking for the 40 sample logs ranked by severity index; check characteristics of the sample logs are summarized in Table 7.

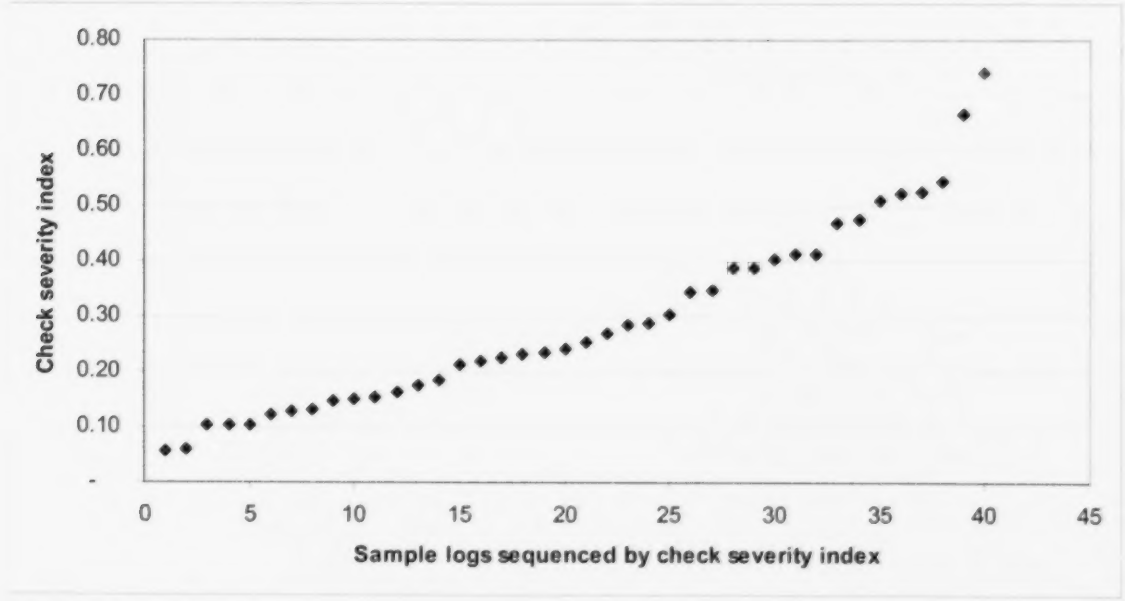

Figure 4: Check severity index of sample logs

Table 7: Check damage indicators for sample logs

	Number of checks	Avg. depth as % of log radius	Avg. length as % of log length	Check severity index
Mean	1.70	66.4	27.7	0.292
Std. Dev.	0.94	14.8	18.4	0.170

To estimate the impact on value recovery of damage resulting from beetle attack, the sample logs were sorted according to increasing check severity along with their associated value yields when sawn with current technologies. This facilitated measurement of the strength of the relationship between severity of checking and value extracted from the log. A linear regression analysis using the least squares method was used to fit a line through the data points representing dependent variable value yield, as shown in Figure 5. The regression analysis yielded an R^2 value of 0.405 for the following equation:

$$y = -0.4023x + 0.9741$$

The R^2 value is an estimate of the proportion of the variation in the observed value yields that can be explained by the check severity index. The index correlates with value yield and has some predictive power, but clearly does not account for all variation in value yield. Although deviations attributable to chance are inevitable, undoubtedly there also are deviations attributable to defect characteristics not captured or not precisely defined by the check severity index.

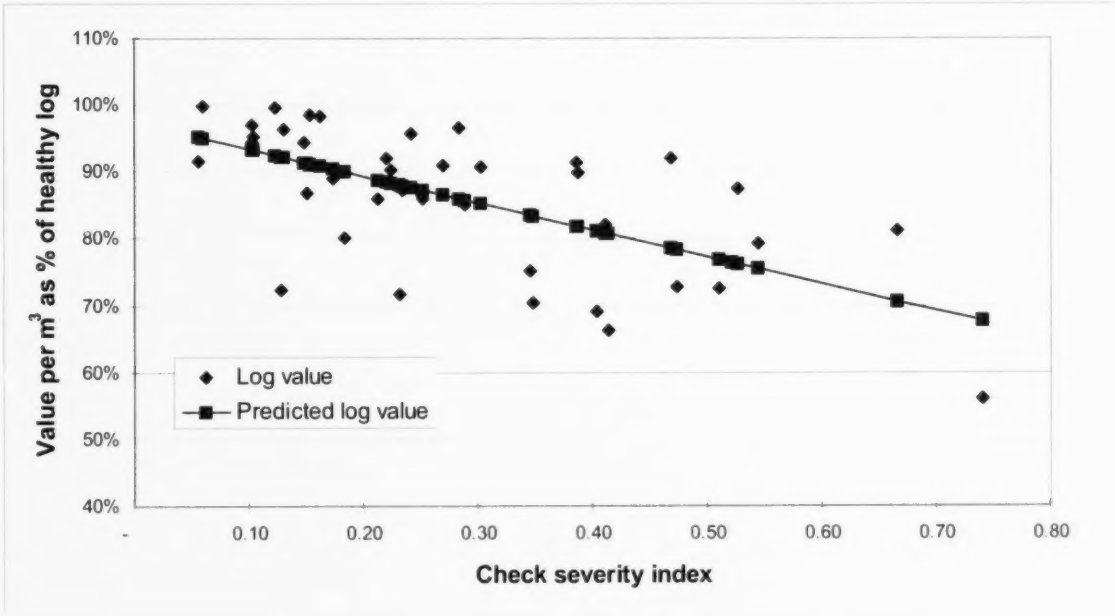

Figure 5: Value recovery and predicted value recovery by check severity index

To further test the significance of the estimate of value yield as a function of check severity, the logs were divided into three damage-level groups representing distinct levels of check severity, as measured by the check severity index. The mean value yield and the variance were calculated for each group so that differences in value yields associated with each group's checking characteristics could be tested for significance. Individual log values using current technologies were again measured as a percentage of the value of the healthy log. The mean and variance of the value yield, as well as the check severity index, are shown for each group in Table 8.

Table 8: Summary statistics for check severity index and value yield by damage level group

Group	Check severity index		Value yield	
	Mean	Variance	Mean	Variance
A	0.127	0.002	0.923	0.006
B	0.266	0.002	0.859	0.007
C	0.496	0.012	0.782	0.012

After confirmation of equality of group variances, an analysis of variance statistical test (alpha = .05) allowed rejection of the null hypothesis that the group mean value yields were equal; the P-value was 0.0012.

5 Conclusions

This investigation has shown that it is possible to estimate lumber value loss as a function of the degree of beetle-induced defects in logs. Checking in a log was the key defect and a check severity index was developed as a research tool to classify logs according to damage level and to facilitate estimation of value yield as a function of the degree of damage. Statistical analysis showed a correlation between the check severity index and the value loss caused by MPB.

The check severity index is a preliminary attempt to develop a method to classify logs based on extent of beetle damage. Although a correlation was found to exist between the degree of checking and a log's value yield, it must be noted that the sample logs did not represent the full extent of checking found in logs from beetle-attacked trees, and that the predictive power of the index when describing severe checking was not tested.

Emerging technologies that can scan logs and lumber to detect beetle-induced defects and calculate breakdown and sawing solutions to minimize defects' negative impact on value yield showed promise and could result in significant uplift in value yield relative to that recovered from current technologies. Although the benefits presented here are undoubtedly overestimated due to the characteristics of the sample logs as well as the idealized model environment, even small percentage increases in returns for beetle-attacked logs can represent millions of dollars, based on conservative estimates that, in coming years, perhaps 25 million m^3 of beetle-damaged logs will be processed annually in the British Columbia interior. If only half of the value uplifts reported here were achieved, nearly $140 million in additional revenue would be available annually to the industry to support and extend continued processing of post-beetle wood.

6 Recommendations

The strength of the correlation between check severity index and value loss due to MPB attack should be validated through further testing using a larger sample of logs with more severe and more varied checking. This would help refine the index, resulting in a stronger correlation and a more robust and accurate predictive tool.

This study estimates theoretical maximum benefits achievable through the use of emerging technologies. A follow-up simulation study should investigate the benefits of a wider range of technologies, with greater focus on their practical application in mill environments. The study should also evaluate the benefits of emerging technologies when logs with more severe checking are processed.

7 Acknowledgements

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8 Appendix 1: External Shape Characteristics of Sample Logs

	Average Small-end Diameter(cm)	Average Large-end Diameter(cm)	Average Sweep (cm/m)	Average Taper (cm/m)	Average Length (m)	Average Volume (dm^3)
1	26.4	35.0	0.6	1.4	6.1	476.4
2	28.8	32.6	0.5	1.2	3.3	243.6
3	27.1	35.5	0.7	1.4	6.2	459.5
14	21.6	24.4	0.7	0.9	3.2	142.4
16	18.0	19.8	0.5	0.6	3.2	93.2
36	23.4	25.9	0.8	0.8	3.2	156.8
37	16.0	20.7	0.4	1.2	3.9	97.7
44	18.6	20.2	0.5	0.5	3.2	106.2
72	14.5	20.2	1.5	1.9	3.0	92.1
160	30.0	36.7	0.7	1.1	6.2	587.9
162	20.9	25.9	0.8	1.6	3.2	138.7
167	22.6	25.8	0.6	1.0	3.2	147.2
188	20.1	27.2	0.7	2.1	3.4	183.9
194	19.9	22.1	0.4	0.7	3.2	108.6
195	20.9	25.9	0.8	1.6	3.2	138.7
199	20.1	27.2	0.7	2.1	3.4	183.9
201	16.8	21.0	0.2	0.9	5.0	136.0
202	17.7	22.4	1.4	1.5	3.2	142.6
204	21.4	22.4	0.5	0.4	3.0	122.8
214	15.8	21.5	0.6	1.4	4.1	119.4
215	22.3	25.2	0.5	0.9	3.3	148.9
220	27.1	35.5	0.7	1.4	6.2	459.5
224	30.0	36.7	0.7	1.1	6.2	587.9
225	30.1	36.8	0.4	1.1	6.2	526.5
231	25.2	32.3	0.6	1.2	6.2	429.1
234	28.6	37.3	0.5	2.0	4.4	370.1
235	26.6	32.7	0.3	1.0	6.2	429.8
236	24.0	26.0	0.5	0.6	3.3	165.7
249	25.2	32.3	0.6	1.2	6.2	429.1
252	23.4	26.1	0.3	0.9	3.0	152.0
253	27.1	35.5	0.7	1.4	6.2	459.5
255	26.4	35.0	0.6	1.4	6.1	476.4
257	22.2	28.0	0.8	1.7	3.4	187.5
258	25.4	27.8	0.8	0.6	4.0	233.1
259	30.0	36.7	0.7	1.1	6.2	587.9
260	29.2	31.7	0.7	0.7	3.7	267.6
263	30.1	36.8	0.4	1.1	6.2	526.5
266	26.6	28.6	0.3	0.6	3.7	224.6
267	25.4	28.7	0.5	0.8	4.4	262.8
268	26.6	32.7	0.3	1.0	6.2	429.8
Avg:	23.8	28.9	0.6	1.1	4.4	280.8
Min:	14.5	19.8	0.2	0.4	3.0	92.1
Max:	30.1	37.3	1.5	2.1	6.2	587.9
StdDev:	4.5	5.8	0.3	0.4	1.4	168.1

9 Appendix 2: Lumber Prices, Grade Outturns and Piece Values

Table A2-1: Lumber prices (FOB Prince George, $CAN/Mfbm. Derived from industry publications and through consultations with industry advisors).

Size	2x3-8	2x3-10	2x3-12	2x3-14	2x3-16	2x3-18	2x3-20
J-Grade	NP	NP	NP	NP	NP	NP	NP
MSR	417	417	417	417	417	432	432
No2&Btr	285	310	311	325	355	325	310
#3 or Utility	216	236	237	248	272	248	236
Econ	138	138	138	138	138	138	138
	2x4-8	2x4-10	2x4-12	2x4-14	2x4-16	2x4-18	2x4-20
J-Grade	416	416	416	416	416	416	416
MSR	387	387	387	387	387	402	402
No2&Btr	320	345	346	360	390	360	345
No3	256	276	277	288	312	288	276
Econ	148	148	148	148	148	148	148
	2x6-8	2x6-10	2x6-12	2x6-14	2x6-16	2x6-18	2x6-20
J-Grade	398	398	398	398	398	398	398
MSR	379	379	379	379	379	379	379
No2&Btr	329	331	354	335	370	343	344
No3	205	207	222	209	231	214	215
Econ	122	122	122	122	122	122	122
	2x8-8	2x8-10	2x8-12	2x8-14	2x8-16	2x8-18	2x8-20
J-Grade	NP	398	398	398	398	398	398
MSR	430	430	430	430	430	445	445
No2&Btr	329	339	359	355	349	370	365
No3	211	218	231	228	225	238	235
Econ	140	140	140	140	140	140	140
	2x10-8	2x10-10	2x10-12	2x10-14	2x10-16	2x10-18	2x10-20
J-Grade	NP	346	418	461	380	372	367
MSR	NP	NP	NP	NP	NP	NP	NP
No2&Btr	331	336	408	451	370	362	357
No3	196	199	241	267	219	214	211
Econ	135	135	135	135	135	135	135

Note: NP – Not produced.

Table A2–2: Grade outturns used to calculate piece values.

		Percent					
		J-Grade	MSR	No2&Btr	No3	Econ	Total
2x3	8	0	38	45	13	4	100
	10	0	54	31	11	4	100
	12	0	51	33	13	3	100
	14	0	50	36	11	3	100
	16	0	42	43	14	1	100
	18	0	46	41	12	1	100
	20	0	46	41	12	1	100
2x4	8	3	14	41	30	12	100
	10	2	23	49	18	8	100
	12	4	35	40	15	6	100
	14	6	34	40	16	4	100
	16	9	37	38	13	3	100
	18	6	39	37	15	3	100
	20	9	46	31	12	2	100
2x6	8	3	14	37	26	20	100
	10	8	27	41	16	8	100
	12	10	24	48	13	5	100
	14	8	25	50	12	5	100
	16	15	29	40	13	3	100
	18	14	31	40	12	3	100
	20	15	38	35	10	2	100
2x8	8	0	0	59	29	12	100
	10	2	22	50	21	5	100
	12	5	25	49	18	3	100
	14	8	25	46	18	3	100
	16	11	29	43	15	2	100
	18	6	25	50	16	3	100
	20	12	31	43	12	2	100
2x10	8	0	0	64	30	6	100
	10	6	0	65	23	6	100
	12	7	0	70	18	5	100
	14	11	0	72	14	3	100
	16	11	0	72	14	3	100
	18	10	0	71	16	3	100
	20	7	0	79	12	3	100

Table A2-3: Piece values.

$/piece	J-Grade	MSR	No2&Btr	No3	Econ
2x3-8	1.28	1.28	1.08	0.85	0.55
2x3-10	1.76	1.76	1.47	1.16	0.69
2x3-12	2.10	2.10	1.78	1.40	0.83
2x3-14	2.50	2.50	2.18	1.71	0.97
2x3-16	2.94	2.94	2.73	2.17	1.11
2x3-18	3.27	3.27	2.82	2.22	1.24
2x3-20	3.55	3.55	2.99	2.35	1.38
2x4-8	1.56	1.55	1.49	1.30	0.79
2x4-10	2.19	2.18	2.11	1.77	0.99
2x4-12	2.73	2.72	2.59	2.15	1.19
2x4-14	3.29	3.27	3.17	2.64	1.38
2x4-16	3.99	3.96	3.95	3.28	1.58
2x4-18	4.35	4.34	4.11	3.41	1.78
2x4-20	4.87	4.85	4.43	3.65	1.98
2x6-8	2.12	2.11	2.04	1.51	0.97
2x6-10	3.13	3.11	2.94	2.00	1.22
2x6-12	4.03	4.01	3.91	2.60	1.46
2x6-14	4.55	4.53	4.33	2.87	1.70
2x6-16	5.62	5.58	5.51	3.65	1.95
2x6-18	6.12	6.07	5.78	3.81	2.19
2x6-20	6.96	6.91	6.54	4.26	2.44
2x8-8	2.90	2.90	2.90	2.16	1.49
2x8-10	4.33	4.32	4.05	2.86	1.86
2x8-12	5.58	5.57	5.27	3.65	2.23
2x8-14	6.49	6.48	6.07	4.21	2.60
2x8-16	7.58	7.57	6.97	4.76	2.98
2x8-18	8.70	8.69	8.21	5.65	3.35
2x8-20	9.96	9.95	9.20	6.21	3.72
2x10-8	3.72	3.72	3.72	2.56	1.80
2x10-10	4.89	4.87	4.87	3.25	2.25
2x10-12	7.29	7.28	7.28	4.72	2.70
2x10-14	9.73	9.70	9.70	6.13	3.14
2x10-16	9.15	9.12	9.12	5.77	3.59
2x10-18	9.98	9.95	9.95	6.35	4.04
2x10-20	11.11	11.09	11.09	6.96	4.49

10 Appendix 3: Optitek Piece Value Calculation

Optitek needs piece values for value optimization purposes. These piece values were derived from $/Mfbm prices of lumber sizes and grades (Appendix 2) and historical grade outturns. Considering historical grade outturns was necessary because the Optitek grading subroutine takes only beetle defects into consideration. On the other hand, other defects (e.g., knots) that affect lumber grade must also be taken into account. The piece values are weighted averages with weights of grade outturns.

To illustrate the method of piece value calculation, Figure A3-1 shows an beetle-killed log with resulting lumber pieces. Wane, blue stain and checks—the defects that limit the lumber grade that Optitek includes in its grading subroutine—are demonstrated.

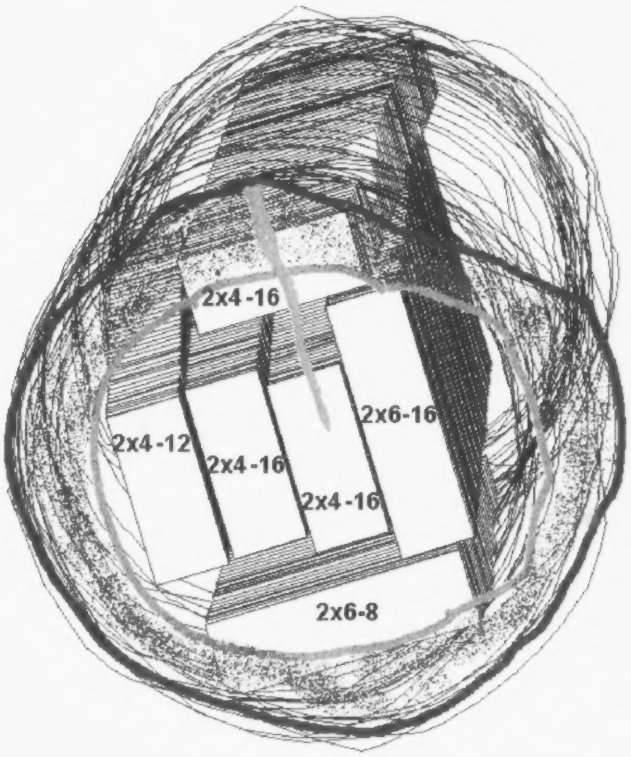

Figure A3-1: Sample log breakdown

For example, to calculate the value of the piece of 2x4-16, second from left in the center cant, we must know its nominal volume (10.67 fbm) and its weighted price per Mfbm. Since this piece has no grade-limiting defects considered by Optitek (i.e., no wane, checks or bluestain) all of the grades listed in Table A3-1 are possible.

Table A3-1: Grade outturns and prices

Grade	Grade outturn %'s	Price
(1)	(2)	(3)
J-Grade	9	416
MSR	37	387
2&Better	38	390
No3	13	312
Economy	3	148
Total:	100	

Based on the grade outturns of Table A3-1 we assume that 100 pieces of 2x4-16 contain 9 pieces of J-Grade, 37 pieces of MSR, 38 pieces of 2&Better, 13 pieces of No3 and 3 pieces of Economy. Thus the calculation of the weighted average price of a 2x4-16, with the highest Optitek grade, per MFBM is as follows:

0.09 x 416 + 0.37 x 387 + . . . + 0.03 x 148 = $373.67/Mfbm.

The piece value of this 2x4-16 piece is:

(373.67 / 1000) x 10.67 = $3.99

Note that, in the above example, we did not know anything about the actual defects of the 100 pieces. We only knew that, as Optitek did not find any grade-limiting defects (wane, checks or bluestain), Optitek graded this piece as the highest Optitek grade. Consider another piece with defect, the 2x4-16 with the check (immediately to the right of the 2x4 piece used as an example above in Figure 1). Assuming that the grade is limited by this check to 2&Better, then the calculation leading to the weighted average price differs and includes the weights from Table A3-2:

0.84 x 390+0.13 x 312 + 0.03 x 148 = $372.39/Mfbm

Table A3-2

Grade	Grade outturn %'s	Price
(1)	(2)	(3)
2&Better	(9+37+38=) 84	390
No3	13	312
Economy	3	148
Total:	100	

The piece value of this 2x4-16 piece with the assumed defects is:

(372.39 / 1000) * 10.67 = $3.97

11 Appendix 4: Log End-views Showing Breakdown Solutions

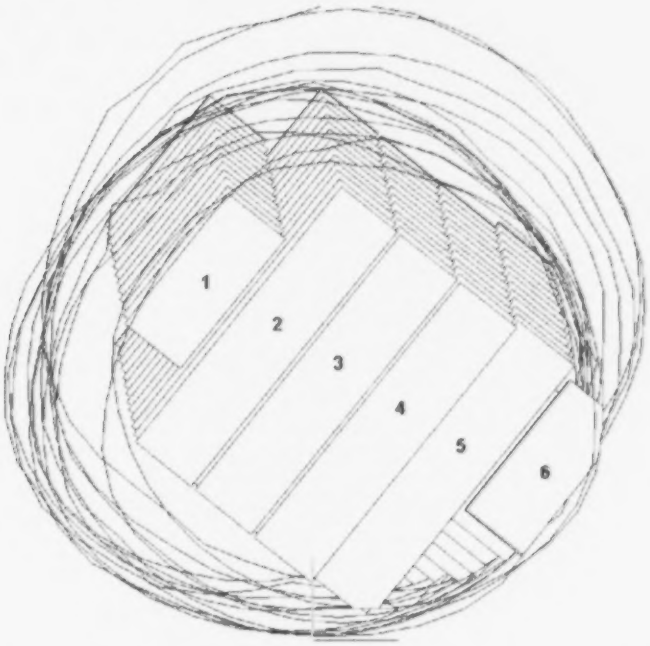

Figure A4-1: Breakdown solution for healthy log processed with current technology

Table A4–1: Lumber yield from healthy log processed with current technology

Healthy log - current technology					
	Optitek grades				
	1	2	3	4	5
Number of pieces	4	--	1	--	1
Piece code	(1, 2, 3, 4)	--	(5)	--	(6)
Value recovery: $44.56 per log / $93.54 per m3 Volume recovery: 116fbm per log / 243.51 fbm per m3					

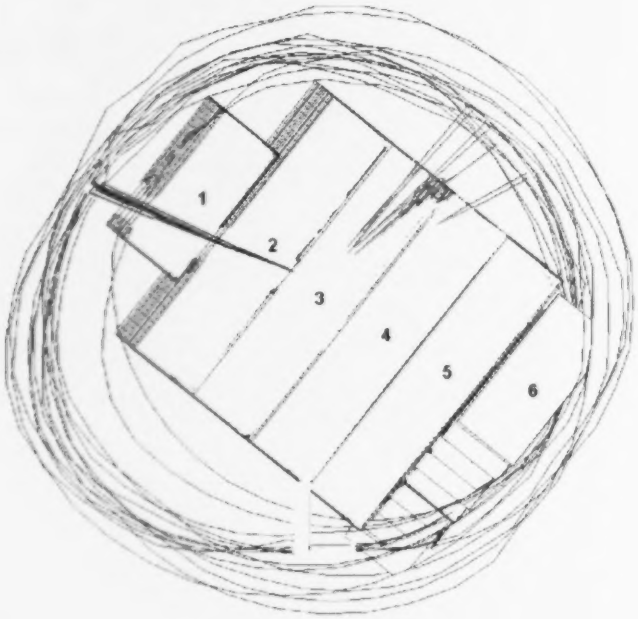

Figure A4-2: Breakdown solution from log with defects processed with current technologies

Table A4–2: Lumber yield from log with defects processed with current technology

MPB-damaged log - current technology					
	Optitek grades				
	1	2	3	4	5
Number of pieces			2	1	3
Piece code			(4, 5)	(1)	(2, 3, 6)
Value recovery: $32.36 per log / $67.93 per m3 Volume recovery: 114.67fbm per log / 240.71 fbm per m3					

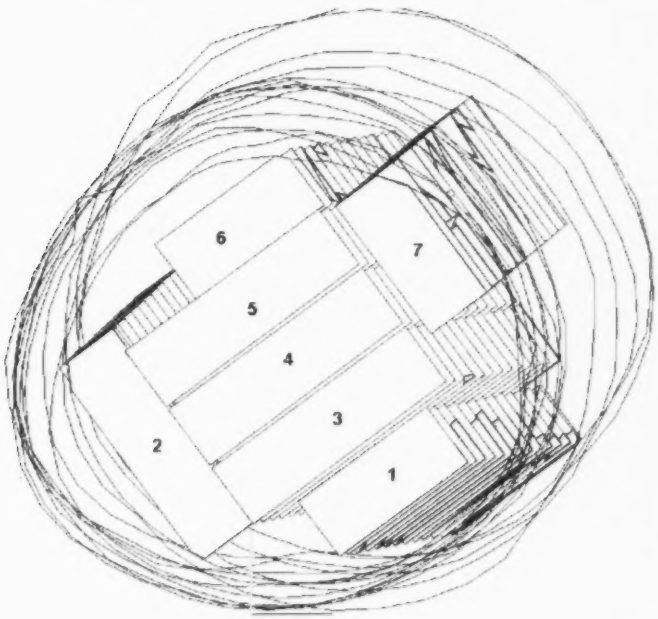

Figure A4-3: Breakdown solution from log with defects processed with future technology

Table A4–3: Lumber yield from log with defects processed with future technology

MPB-damaged log - future technology					
	Optitek grades				
	1	2	3	4	5
Number of pieces	1	4	1	1	--
Piece code	(4)	(1, 2, 3, 6)	(5)	(7)	--
Value recovery: $40.84 per log / $85.73 per m3 Volume recovery: 108 fbm per log / 226.72 fbm per m3					

12 Appendix 5: Sawing Simulation Results

Table A5-1: Absolute value recoveries

Log No.	Value recovery ($/m^3)			Current loss ($/m3)	Decrease in loss through emerging technology ($/m3)
	Healthy log	Damaged log - current technology	Damaged log - emerging technology		
1	93.54	67.93	85.73	25.61	17.8
2	111.17	90.31	101.44	20.86	11.13
3	108.83	83.17	97.23	25.66	14.06
14	105.38	95.05	103.55	10.33	8.50
16	100.04	72.24	96.28	27.8	24.04
36	104.20	99.80	99.80	4.40	0.00
37	85.80	68.80	84.27	17.00	15.47
44	106.88	76.55	106.40	30.33	29.85
72	60.23	59.37	59.37	0.86	0.00
160	123.16	92.38	108.26	30.78	15.88
162	98.99	95.32	96.18	3.67	0.86
167	102.67	100.83	102.39	1.84	1.56
188	96.57	88.96	94.56	7.61	5.6
194	104.84	101.34	101.34	3.50	0.00
195	98.99	98.78	98.78	0.21	0.00
199	96.57	93.64	95.49	2.93	1.85
201	111.91	102.50	111.91	9.41	9.41
202	77.83	51.61	77.20	26.22	25.59
204	84.45	77.69	79.81	6.76	2.12
214	89.02	49.91	83.41	39.11	33.50
215	92.14	91.67	91.67	0.47	0.00
220	108.83	94.92	104.15	13.91	9.23
224	123.16	101.15	111.67	22.01	10.52
225	121.52	109.27	115.04	12.25	5.77
231	102.65	74.34	90.07	28.31	15.73
234	126.46	108.57	120.62	17.89	12.05
235	114.16	107.64	109.57	6.52	1.93
236	113.50	97.45	106.44	16.05	8.99
249	102.65	97.69	99.72	4.96	2.03
252	88.65	61.20	80.16	27.45	18.96
253	108.83	102.62	106.21	6.21	3.59
255	93.54	81.72	90.20	11.82	8.48
257	100.34	91.01	97.41	9.33	6.40
258	105.16	73.88	98.47	31.28	24.59
259	123.16	112.07	113.99	11.09	1.92
260	98.20	77.83	91.51	20.37	13.68
263	121.52	105.61	117.38	15.91	11.77
266	98.82	90.18	93.96	8.64	3.78
267	113.96	96.92	107.95	17.04	11.03
268	114.16	101.47	108.55	12.69	7.08

Table A5-2: Value recoveries as a proportion of healthy log value

Log number	Value Recovery	
	Damaged log as % of healthy log – current technology	Damaged log as % of healthy log – emerging technology
1	72.62	91.65
2	81.24	91.25
3	76.42	89.34
14	90.2	98.26
16	72.21	96.24
36	95.78	95.78
37	80.19	98.22
44	71.62	99.55
72	98.57	98.57
160	75.01	87.9
162	96.29	97.16
167	98.21	99.73
188	92.12	97.92
194	96.66	96.66
195	99.79	99.79
199	96.97	98.88
201	91.59	100
202	66.31	99.19
204	92.00	94.51
214	56.07	93.7
215	99.49	99.49
220	87.22	95.7
224	82.13	90.67
225	89.92	94.67
231	72.42	87.74
234	85.85	95.38
235	94.29	95.98
236	85.86	93.78
249	95.17	97.15
252	69.04	90.42
253	94.29	97.59
255	87.36	96.43
257	90.7	97.08
258	70.25	93.64
259	91.00	92.55
260	79.26	93.19
263	86.91	96.59
266	91.26	95.08
267	85.05	94.73
268	88.88	95.09

13 Appendix 6: Check Damage Indicators

13.1 Indicators of check damage

Log number	Number of checks	Average check depth %	Average check length %	Check severity index
1	3	61.0	26	0.474
2	2	54.6	64	0.666
3	2	72.0	31	0.522
14	2	71.3	14	0.224
16	1	87.0	15	0.128
36	1	68.3	29	0.242
37	1	77.4	24	0.184
44	1	37.5	58	0.232
72	1	99.3	15	0.153
160	5	66.7	10	0.345
162	1	88.2	14	0.131
167	1	40.9	27.4	0.162
188	1	43.7	45	0.220
194	1	90.0	29	0.284
195	1	39.7	14	0.060
199	1	75.3	14	0.103
201	1	59.9	9	0.056
202	2	60.1	29	0.414
204	2	74.5	31	0.468
214	1	62.9	100	0.740
215	1	68.2	14	0.123
220	2	68.0	17	0.234
224	2	66.0	29	0.412
225	3	53.6	24	0.387
231	3	60.9	26	0.510
234	1	54.7	42	0.252
235	1	66.9	15	0.102
236	1	74.8	28	0.213
249	1	29.4	33	0.104
252	1	86.3	46	0.404
253	2	51.3	13	0.148
255	1	73.9	60	0.526
257	3	74.1	14	0.303
258	1	74.7	46	0.348
259	2	68.5	18	0.270
260	4	71.2	19	0.544
263	2	67.2	11	0.150
266	2	72.9	25	0.386
267	2	68.7	21	0.288
268	2	75.6	11	0.174

13.2 Calculation of check severity index

Checking is unique to each tree, hence careful sampling techniques are required to describe the severity of checking in a log. Due to the absence of an accepted definition of severity of checking, in this project, the following definition has been derived:

Let S be the Checking Severity for any log, and let S have range [0 <= S <= 1.0].

Let L = log length,

n = number of checks in the log,

Li = length of check ci

Di = depth of check ci

Ri = radius of the log

Consider the ratio of (D_i / R_i) at a particular point along some check c_i.

Define check depth weighting factors d_i to be the maximum value of all of the (D_i / R_i) measured along the length of check c_i

$$\mathbf{d_i = maximum\ (\ D_i\ /\ R_i\ )}$$

Similarly, let check length weighting factors w_i for c_i be given by:

$$\mathbf{w_i = L_i\ /\ L}$$

The check severity si can be formulated as $d_i \bullet w_i$ to represent a normalized area.

Then log checking severity S is defined as:

$$\boxed{S = (1/n)\ \Sigma\ s_i}$$

The behavior of S for a log with one check c_1:

1) As L_1 -> L, then S -> D_1 / R_1, where [0 <= S <= 1.0]

2) As L_1 -> 0, then S -> 0

3) As D_1 -> 0, then S -> 0

4) As D_1 -> R_1, then S -> L_1/L

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